EXPERIMENTS ON FULL-SIZED TIMBER TRUSSES.

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THE ordinary timber truss used in this country for the support of roofs of moderate span—say up to 40 feet—is not, theoretically, an economical structure. If, however, requirements of practice necessitated modification of theory, there would be every reason why the present method of design should be continued. The object of the experiments here described was to ascertain whether trusses, as constructed according to the dimensions generally accepted in English practice, had any advantage, from a practical point of view, over others designed more strictly in accordance with theory, and more economical of material.

The dimensions usually accepted are those laid down by Tredgold, who wrote his great work on Carpentry in the early part of this century. In 1844 this book was officially adopted as the text-book to be used by the Engineer Department of the Army, by order of the Board of Ordnance, and it has been accepted ever since as the standard authority on the subject. The chapter on roofs in that book, after stating the objects of a roof, begins by observing "that in practice roofs are generally made too heavy, and that he will do a most acceptable service to his profession who will show how to retrench and execute the same roof with the smallest quantity of timber; he will by this take an unnecessary load off the walls, and a large and useless expense from the owner." It was to this end that the experiments were directed.

The ordinary king-post truss is dismissed by Tredgold in a very few lines. He refers to a diagram shown in fig. 1 [p. 115]. He states that in such a roof, up to a span of 30 feet, neither the purlins nor the points of support of the tiebeam come too far apart; and he then refers to tables of scantlings for the various members of the truss, at different spans, but under the same conditions of slope, roof-covering, spacing of trusses, and timber. He does not assign any reason for adopting the scantlings which he gives.

The queen-post truss is similarly briefly described.

On these brief paragraphs the whole of ordinary English practice is based.

On referring to fig. 1, it will be seen that (1) the section of the principal rafter P is of much smaller scantling than the tiebeam A; (2) that the struts, B B, are very light, and their centre lines, if prolonged, would intersect at a point considerably above the centre of the tiebeam; (3) that the purlins, C C, do not come vertically over the struts; (4) that the tiebeam and the principal are united at the heel by a strap which is fastened by a comparatively small bolt through the tiebeam.

In fig. 2, in addition to the above points, we see that (5) the straining beam, S, though somewhat thicker than the principal, is not so thick as the tiebeam.

All the above points are theoretically unsound, for the following reasons:—

(1) The actual amount of stress borne by the principal under any conditions of loading is greater than that borne by the tiebeam. This follows from consideration of the equilibrium at the junction, shown in fig. 3, which represents the triangle of forces at the joint.

(2) The struts may not always have the same amount of stress—*i.e.* if there is a greater load on one side of the roof than on the other, one of the two will have a greater stress than the other, and the effect of the arrangement of the joint will be that there will be both bending and shearing stress set up at the foot of the king-post, which it is not designed to resist. In any case the stress on the struts will be eccentric.

(3) In all cases of direct loading, eccentricity of stress tends to cause bending, and increased intensity of stress. Hence, where the purlins are not directly over the struts, not only will the latter tend to fail the sooner by lateral flexure, but there will be combined stress set up in the principals, which will also tend to fail sooner than they otherwise would.

(4) Although in this form of fastening the strap is, rightly, inclined as much as possible to the horizontal, the small size of the bolt is a serious objection, since it would have to transmit the greater part of the tensile stress of the tiebeam, and its bearing area on the timber is not sufficient to prevent the crushing of the fibres adjacent to it.

(5) The straining beam is a long column under a very considerable amount of compression. It must be designed, therefore, according to the principle of long columns of timber fixed at the ends. The dimensions given in the tables of scantlings are rarely sufficient to meet the maxima stresses. Tredgold's Tables are based upon the supposition that (1) the trusses are 10 feet apart, (2) the roof-covering is slate, (3) the pitch about 27°, (4) the timber yellow fir. He states that the scantlings are the smallest that ought to be used for good Riga or Memel timber.

It is not stated whether there is a ceiling. It may be reasonably supposed that there is—and this is an important point, because under such circumstances the provision of a deep tiebeam is desirable, so as to withstand the vertical deflection which would be caused by the weight of the ceiling. It is, however, possible to obtain stiffness without going to the expense and weight of the heavy timbers given by Tredgold in his tables.

The use of the tables being limited, in any case, to certain definite conditions of material, roof-covering, slope and spacing of trusses, it is evidently desirable that some general rules or formulæ should be prepared, whereby the scantlings of roofs under any circumstances might be arrived at. Such formulæ have been published, and have been in use for some time. They are shown in an Appendix [pp. 125–26].

Before being perfectly certain, however, that trusses based upon theoretical principles could be more economically made than those designed by Tredgold, it was necessary to subject specimen trusses of both kinds to tests. It was further necessary to have these tests carried out on full-sized trusses, as models might give unfair results.

In order to secure the best results in the theoretical truss, it was necessary so to design it that, at the various joints, the axes of the various members should intersect on the central fibres of other members, and thus insure concentric stress. To this end the design of the joints was reconsidered. Fig. 4 shows the modified form of the joint at heel of principal. In this case the stress on the strap is a minimum, owing to its horizontal position. The bolt passes through a chock of wood between the halves of the tiebeam,* and this chock is housed for a short depth in these halves at either side to prevent slipping. Fig. 5 shows the arrangement at the foot of the king-post.

The first experiments were carried out on trusses resting on two brick pillars about 2 feet

* In this design a double tiebeam is substituted for the single one in Tredgold's design.

square and 6 feet high. In the brickwork near the ground was built an ordinary I-rolled steel beam. On the truss, at points corresponding to the positions of the purlins, were

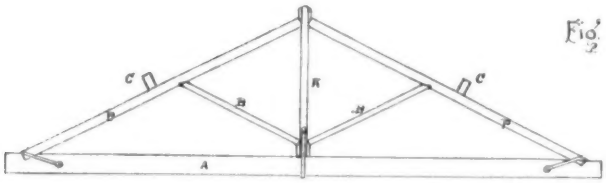


Fig. 1

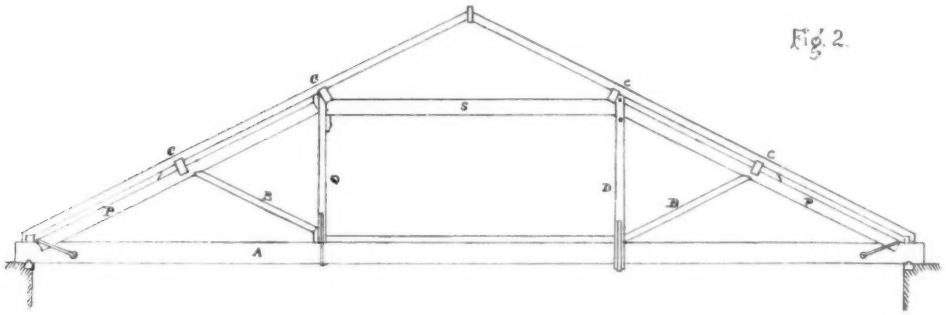


Fig. 2.

Fig. 3.

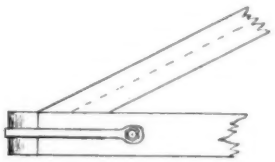


Fig. 4.

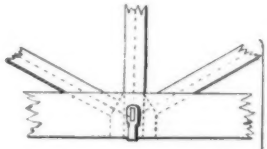
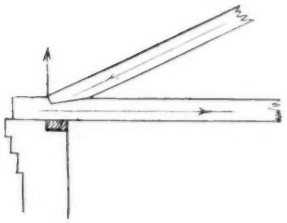
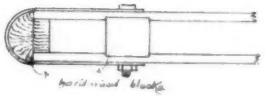


Fig. 5





(Figs. 6 & 7 on subsequent pages)

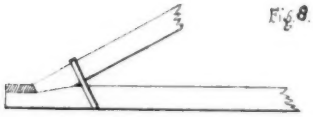


Fig. 8.

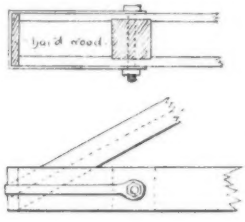


Fig. 9.

suspended Duckham's patent weighing-machines, which had a block and tackle suspended from them, with a corresponding block hooked on to a screw coupling fastened to the I-beam.

The tackle was hauled up as tight as it would go, and extra pressure was put on by screwing up the coupling.

This method was unsatisfactory, because it was found that if any load or fastening slipped, the man working the screw coupling was exposed to considerable danger, and also the Duckham weighing-machines were not very sensitive. It became necessary to devise some other plan.

A scheme was at first worked out whereby the pressure would be produced by two sets of treble blocks worked by windlasses, and the amount of the pressures registered by helical springs; but there were practical difficulties which caused this plan to be superseded by another, which, although it had disadvantages, was practicable, and gave interesting results.

By this scheme an ordinary 7-inch steam gauge was connected with a shallow cylinder in which worked a ram or piston 50 square inches in area. As the steam gauge registered the pressure per square inch, any readings indicated on the dial would be one-fiftieth of the actual pressure on the cylinder. Each of these cylinders was carefully tested by a system of levers. It was found to give very accurate results.

The actual pressure brought to bear upon the cylinders was produced by hydraulic jacks, worked by men pulling a rope attached to the handle of the jack. During the tests no workmen came near the apparatus, so that if anything gave way, nobody could be hurt. No accidents occurred.

The amount of pressure required is considerable. If we consider each truss to be spaced at 10 feet, in accordance with Tredgold's data, and the weight of the roof covering, including occasional loads, to be 40 lbs. per square foot, we have 400 lbs. per foot run of slant length, whatever the span may be. In a 28-foot span, the slant length of the common rafters is about 32 feet (the rise being 7 feet), so that the load amounts to 12,800 lbs. Of this, half, approximately, will be borne by the purlins, and half will rest on the pole plates. None will be borne vertically at the ridge, as usually constructed. Each purlin, therefore, will have to bear 3,200 lbs.; and as the roof must be designed with a reasonable margin of safety, it was clearly necessary that the testing apparatus on each purlin should be able to stand 12,000 or 13,000 lbs.

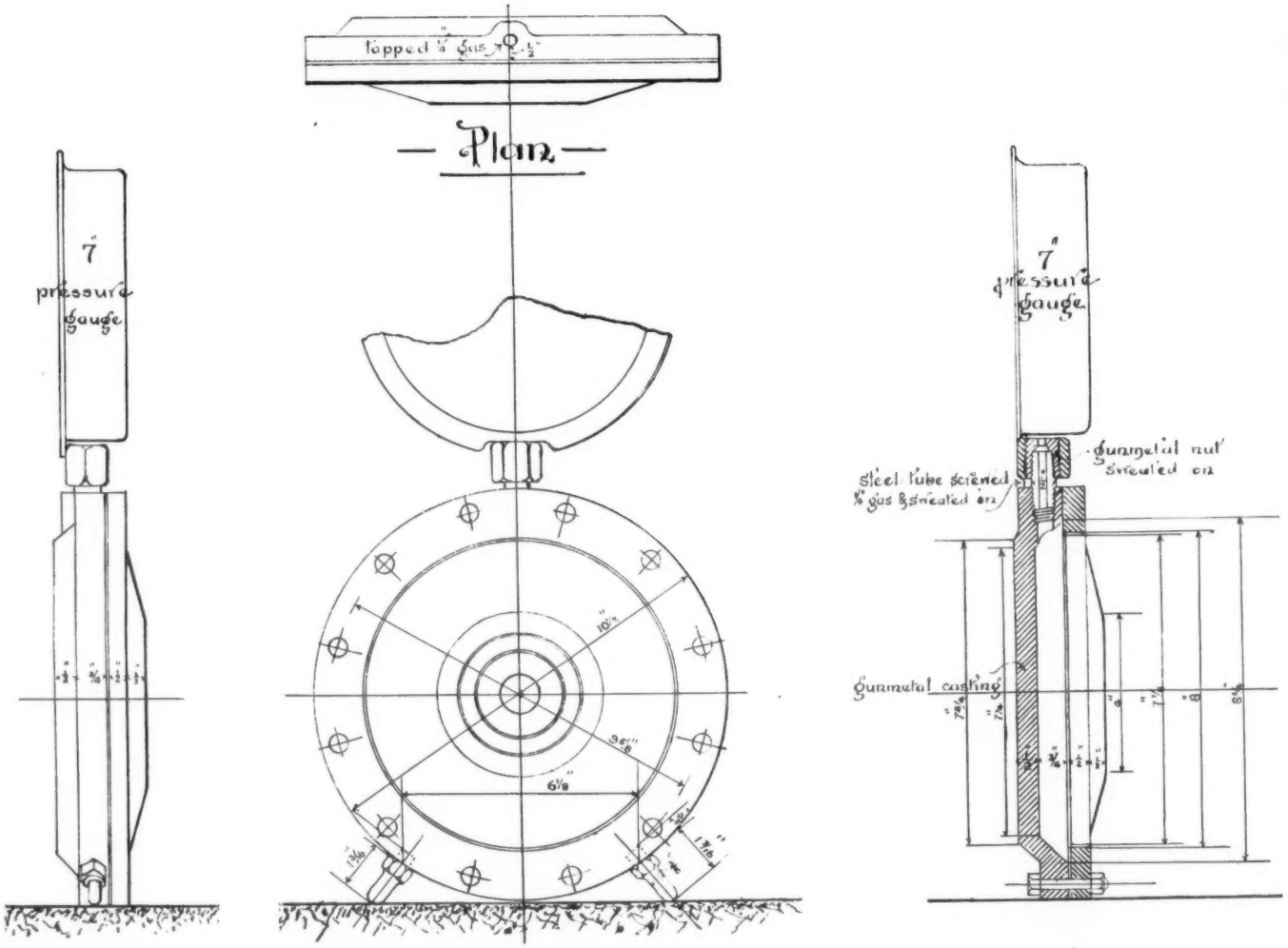
The truss, then, was laid on its side as shown in fig. 7 [p. 119]. A rolled steel beam was used for taking the pressures, and steel straps or sling bars 4 inches by $\frac{5}{8}$-inch total, or 3 inches by $\frac{5}{8}$-inch net section, connected the ends of the truss with the steel beam. The hydraulic jacks and rams were introduced at the positions of the purlins.

It will be observed that the sling bars have slots cut in them, so as to be available for different sizes of trusses. A packing piece of steel was introduced at the place where the wall plate would ordinarily come, but there was no substitute for the pole plate. This fact placed the tested truss at a slight disadvantage, in respect of rigidity, with the ordinary truss in a building, because, as tested, its rigidity was that of a *supported* beam, whereas really the effect of the pole plate and its superincumbent load is to *fix* the ends, or at all events to make them nearly fixed, and, of course, greatly to reduce the deflection.

(1) The first test on this system was carried out on a king-post truss made after the usual pattern, but with principal rafter and tiebeam of the same scantling. This truss was 29 feet span, the principals and tiebeam being both 5 inches by 4 inches, and struts 4 inches by 4 inches, the heel straps $1\frac{1}{4}$ inch by $\frac{1}{4}$ inch, with plates 3 inches by 4 inches below, and $2\frac{3}{4}$ inches by 4 inches above. These heel straps were made at right angles to the principals. The end of the tiebeam projected for about 9 inches beyond the heel of the principal.

The object of this test was to ascertain whether the tiebeam of a truss, if of the same scantling as the principal, would be likely to fail; and if so, where.

When the pressure reached 12,000 lbs. on each side, the end of the tiebeam sheared off



Side Elevation.

Front Elevation.

Section.

FIG. 6.—HYDRAULIC BALANCE. SCALE ½ FULL SIZE.

as shown in fig. 8 [p. 115]. At the same time, on the other side, the plates both above and below crushed into the timber. There was no indication of any other failure in the truss. The pressure on the plates was very great, amounting to nearly 5,000 lbs. to the square inch ($12{,}000 \times \text{cosec } 27^\circ \times \cot 27^\circ \div 2\frac{3}{4} \times 4 = 4{,}974$), which is more than the ordinary crushing resistance of fir, transversely to the grain. Apparently on one side the straps were doing all the work of resisting the thrust, and transmitting it to the tiebeam; while on the other side the strap was not so tight, and the joint in the timber had to take at least part of the stress, which amounted to about 24,000 lbs. The area to resist shearing was 4 inches by 9 inches = 36 square inches, hence the stress intensity was $24{,}000 \div 36 = 668$ lbs. The ultimate resistance of fir to shearing along the grain is 500 lbs. per square inch: so that, if the straps were at all loose (as in practice they might easily be), failure in this particular way would be almost inevitable.

The actual maximum weight which the truss would have to bear in a roof would be about 6,600 lbs. over each purlin: so it may be said to have been tested to about twice its maximum load.

All that could be said to have been proved by this test was that it showed in such a truss the scantlings of the various members were quite sufficiently proportioned, but the joint was weak. Tredgold's joint, *with a large bolt*, would have held, no doubt.

(2) The next test tried was the same truss (span 29 feet), except that, instead of the solid tiebeam, planks 5 inches by $1\frac{1}{2}$ inch were substituted, with a horizontal strap, 1-inch bolts, and end blocks. The latter were not of the semicircular shape shown in fig. 4, but of the angular shape shown in fig. 9, with wedges of hard wood tightening up the whole. This was very speedily proved to be a failure. At about 7,500 lbs. on each side the pressure bent the straps and split the wedges. This showed the necessity of some modification of the form of block, and the semicircular form then introduced has since been used with most satisfactory results.

(3) The third trial was a truss of 28-feet span, with 6-inch by $3\frac{1}{2}$-inch principals, 4-inch by $2\frac{3}{4}$-inch struts, $11\frac{1}{2}$-inch by 6-inch tiebeam, 6-inch by 4-inch king-post—in fact, exactly as given in Tredgold's tables.

This truss showed signs of weakness at 6000, lbs. on each purlin. At this pressure the struts buckled and crushed the fibres at the foot of the king-post. When the pressure reached 7,500 lbs. on each side, one of the principals, which had bent into a sinuous curve, split at a tight knot, and no further resistance was afforded.

This truss showed great stiffness as a whole, on account of the heavy tiebeam, but the fact of the failure having occurred so early in the operation prevented the observation of the deflection at the same pressure as some others which have been experimented on.

The fact of its having failed at a tight knot is worth noting, for it shows that the old idea that tight knots are not injurious is quite a fallacy. This has been confirmed by several similar observations.

This test was also important in showing that the weakness of the truss lay in the insufficient scantling of the compression members, and in their unscientific proportions—viz. 6 inches by $3\frac{1}{2}$ inches and $4\frac{1}{2}$ inches by $2\frac{3}{4}$ inches. These struts buckled in the direction of their least dimension.

(4) Truss 28 foot span. Principal rafters 5 inches by 6 inches, struts 5 inches by 4 inches, tiebeam double, each plank 8 inches by 2 inches, king-post 5 inches by 2 inches. This truss was for the same span as the former one, but the dimensions were calculated according to theoretical principles.

The strap at the foot of the principal was horizontal, 2 inches broad with 2-inch bolt. A bolt $1\frac{1}{8}$ inch was hardly strong enough.

This truss, when loaded with 9,000 lbs. on each side, showed some signs of weakness, the principal beginning to buckle, but it did not actually fail until, at pressures between 11,000 and 12,000 lbs., the hydraulic jacks began to leak so much that no further pressure could be

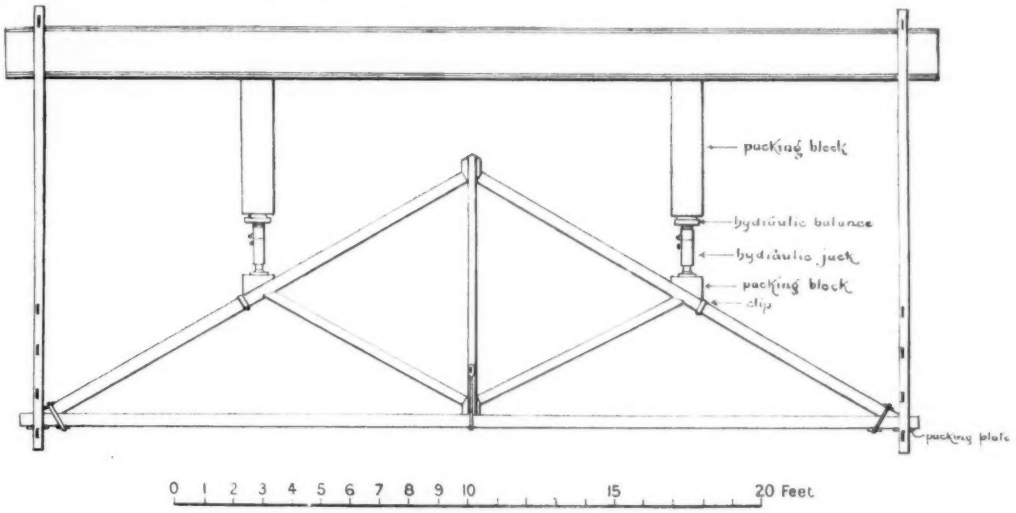


FIG. 7.—ARRANGEMENT FOR TESTING ROOF FRAMES.

attained. At this pressure the total deflection of the truss was considerable—viz. 1·75 inch; but it recovered its original form as soon as the loads were removed.

Comparing this truss with the one previously tested (No. 3) we see that there was a considerable saving in cost as well as increase of strength. It would be, perhaps, unfair to base

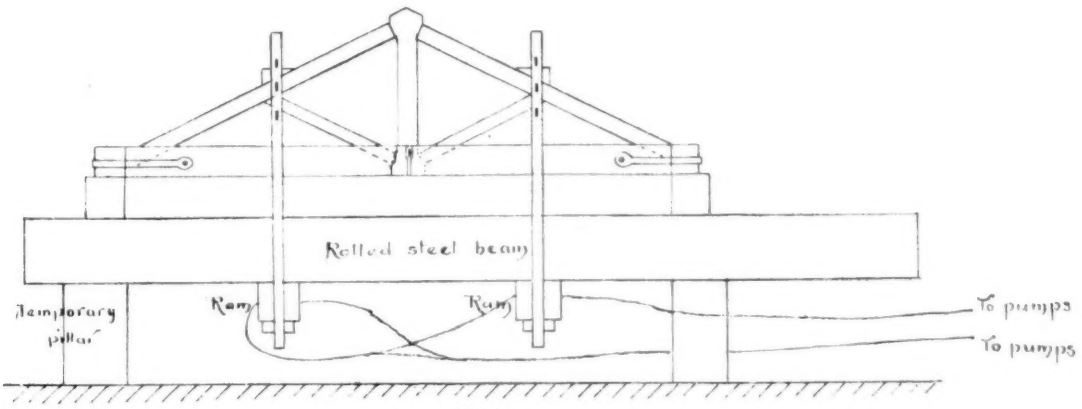
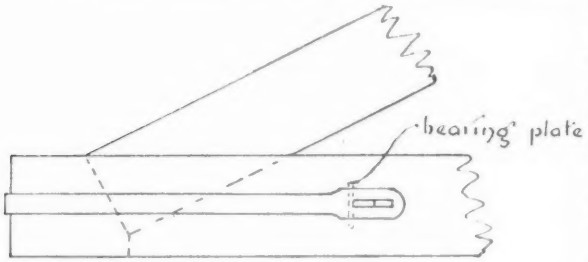


FIG. 10.

any general deduction from the comparison; but it may be said that, so far as we have gone, theory had given better results than practice. Truss No. 3 had failed under a load equivalent to 75 lbs. per square foot of roof, while truss No. 4 had borne without failure a weight corresponding to a uniform load of 137 to 140 lbs. per square foot.

At this stage of the experiments it was thought advisable to make some alterations in the methods employed. The fact of the hydraulic jacks leaking at high pressures was very unsatisfactory, and it was considered also very disadvantageous to have the truss lying on its side, a position which might suffice for purposes of comparison, but which would not give such true results as to the actual bearing power of the truss as would be the case if the truss were in a vertical position.

Special hydraulic rams were cast, and connected by means of ordinary lead gas-piping with pumps in an adjacent building, in which were also fixed on each system of pipes the 7-inch gauges as before. It was therefore possible to work the pumps at some distance from the truss, watching the effect from a window. The trusses were placed vertical, as they would be in a building. The rolled steel beam against which the rams worked was raised on props a few feet above ground, the truss was supported on blocks which rested on the steel beam, and the steel straps, as before, passed over the truss and under the hydraulic rams. The difference between this method and the former one was that in this the steel straps pulled at the truss, whereas in the other the hydraulic jacks pushed at the truss, in both cases exercising pressure at those places where the purlins would ordinarily come.



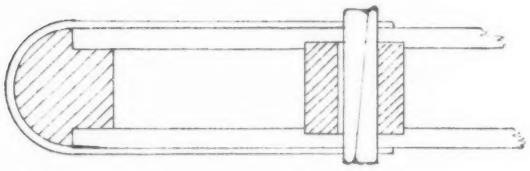
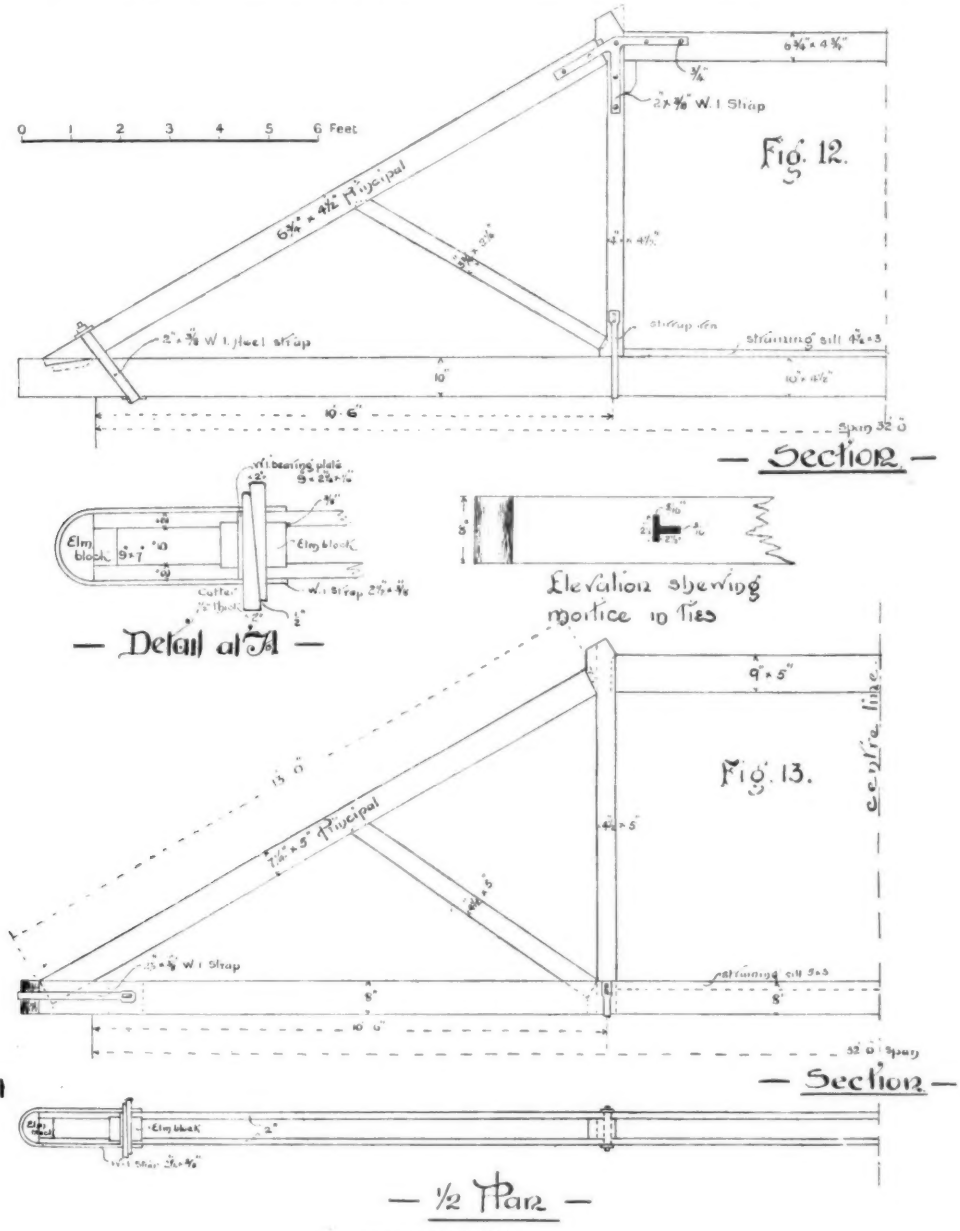


FIG. 11.

The first truss to be experimented on in this manner was the same (No. 4) as had been previously experimented on, and had then withstood any attempt to destroy it. At 10,800 lbs. the truss began perceptibly to buckle, and at 17,850 lbs. the principal on one side gave way by combined crushing and bending. The whole truss had distorted laterally to a very great extent, which would no doubt have been considerably diminished if it had been stiffened, as in the case of a roof in actual use, by lateral purlins, &c. The weight of the two hydraulic rams and sling bars was 11½ cwt.= 1,288 lbs., so the total weight on the truss at the time of failure was 19,138 lbs., or about 9,500 on each purlin. This amounts to a direct thrust of 21,600 lbs. on each principal, or 1,080 lbs. per square inch. The truss was calculated to bear a safe load of 600 lbs. per square inch. The failure was found to have taken place at small knots. The truss had been lying about exposed to wintry weather for some months, and the timber had shrunk a little at the foot of the principals, and this had made the joint there somewhat loose.

The total weight at which this truss had failed—19,138 lbs.—was, it will be observed, considerably less than the weight it had withstood on a previous trial, when it had borne upwards of 22,000 lbs. without failure. The reason apparently was that the shrinkage of the joints had made local pressure more severely felt on some parts of the structure, with the accompanying disadvantages of eccentric loading. This pointed to the necessity of so designing the joint as to be able to tighten it up at will.

The next trusses experimented upon were 24-feet span.
One of these (No. 5) was of Tredgold's dimensions: Principals 5 inches by 4 inches, struts



QUEEN-POST TRUSSES.

4 inches by 2½ inches, king-post 5 inches by 3½ inches, tiebeam 10½ inches by 5 inches. Cost £2. 16*s*. 1*d*.

Under a total pressure of about 15,600 lbs. the principal rafter showed signs of splitting. At 20,000 lbs. the lateral deflection as a whole was about 4 inches. At 22,000 lbs. the truss absolutely failed by cracking along the principals, beginning at a knot just above the junction of the struts. The vertical deflection was 2½ inches. Taking the ultimate strength of the truss at 22,000 lbs., the *efficiency—i.e.* ultimate strength divided by cost in shillings—may be taken as 393. The weight per square foot at which this truss failed was about 84.

No. 7 was also 24 feet span, but considerably lighter, the scantlings being as follows:—

FIG. 14.—TREDGOLD'S TRUSS, 32 INCH SPAN, UNDER PRESSURE OF 31,920 LBS., SHOWING LATERAL TWISTING AND CRIPPLING OF JOINT AT HEEL OF PRINCIPAL.

Principals, 4 inches by 4 inches; struts, 4 inches by 3 inches; king-post, 4 inches by 3 inches; tiebeam double, 8 inches by 1½ inch. Cost £2. 3*s.* 5*d.*

At 15,000 lbs. there was no sign of weakness, but at 20,000 lbs. the lower end of the principal pushed the heel strap into an inclined position. Taking this as failure, though no doubt the truss might have borne more, we see that the efficiency is 463, and the weight per square foot of roof surface which the truss could bear is 75 lbs. The resistance per square inch of the principal rafter works out to 1,403 lbs., whereas in No. 6 the same resistance is 1,240 lbs. The difference is no doubt due to the eccentricity of loading in the older pattern.

Failure in No. 7 was caused, however, by the same defect as noted previously in this

pattern of truss—*i.e.* being unable to tighten up the joint at the junction of principal and tiebeam. This led to a modified design of this joint, shown in fig. 13, where a gib and cotter joint is given horizontally, bearing against a vertical plate which supplies the necessary bearing area to resist the pull.

(8) This was a queen-post truss 32 feet span, of the type proposed by Tredgold, with scantlings as follows:—Principals, $6\frac{3}{4}$ inches by $4\frac{1}{4}$ inches; struts, $3\frac{3}{4}$ inches by $2\frac{1}{4}$ inches;

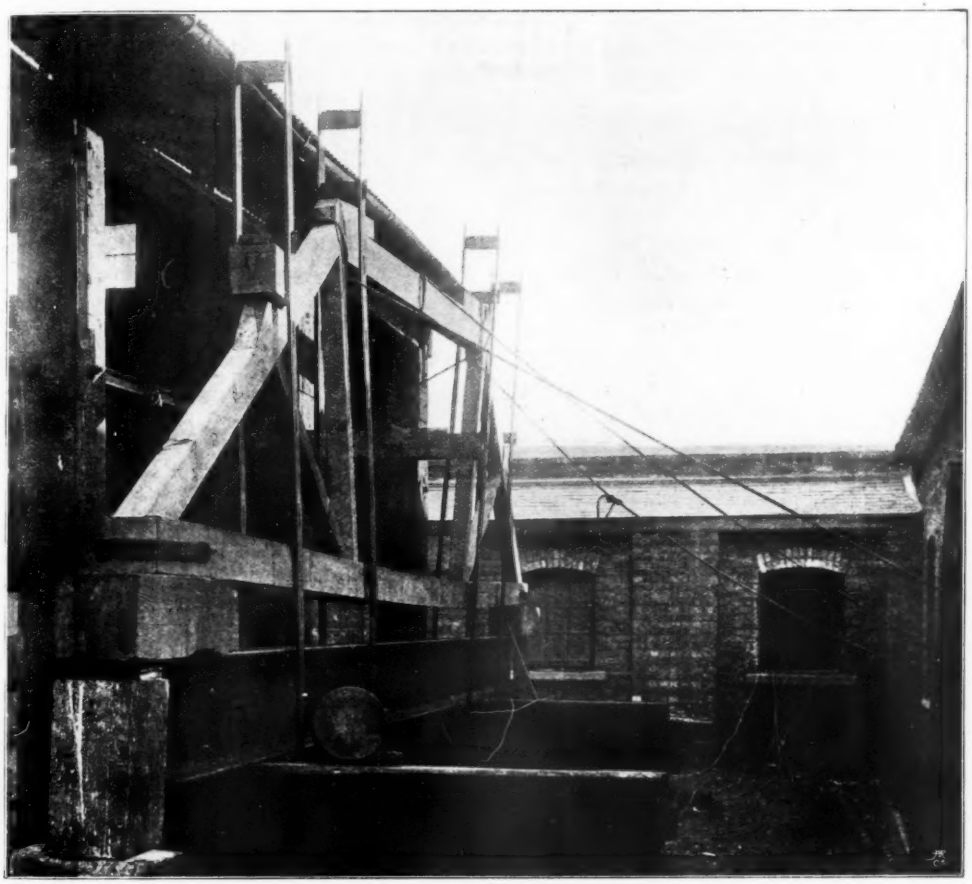


FIG. 15.—SPECIAL TRUSS, 32-INCH SPAN, UNDER PRESSURE OF ABOUT 24,000 LBS.

tiebeam 10 inches by $4\frac{1}{2}$ inches; queen-posts, 4 inches by $4\frac{1}{2}$ inches; straining beam, $6\frac{3}{4}$ inches by $4\frac{3}{4}$ inches; straining sill, $4\frac{1}{2}$ inches by 3 inches. See fig. 12.

The great difficulty in this test, and in that of a truss of similar span designed with a double tiebeam, was to prevent lateral deflection, or buckling of the truss as a whole. Endeavour was made to keep the structure as stiff as possible by means of stays formed of blocks and tackle, on both sides; but even this was not thoroughly efficacious, and the trusses were not, in either case, tested to actual destruction, although they were both crippled. The cost of this truss was £4. 10*s*. 3*d*.

At a pressure on the whole truss of 24,780 lbs. the fibres at the ends of the struts began to be crushed, and the queen-posts showed signs of shearing along the grain at the places where the struts were tenoned into them.

At 31,920 lbs. the joint at the foot of the principal was crippled, the fibres of the timber being crushed, and the strap strained and bent.

The truss as a whole was now so distorted that it was hardly feasible to continue any further test. The truss was taken down and a new strap put in at the heel of the principal, inclined as much as possible to the horizontal. It was again tested, but the strain it had already been subjected to had evidently had an injurious effect on its elasticity, for after the pressure had reached 37,680 lbs. it buckled laterally to such an extent that it slipped off its bearings, without, however, any actual fracture.

(9) This truss, shown in fig. 13, was for the same span as No. 8, but it had a double tie-beam, stouter principals and other compression members, and less ironwork.

This truss was tested twice, and exhibited even more than the former one the tendency to twist laterally, owing doubtless to the absence of iron at the joints. There was no failure of any of the joints or of any of the members, and it is probable that if it could have been kept true in a lateral direction, it would have exhibited very great strength.

At about 30,000 lbs., however, the lateral twisting caused the temporary props on which the whole was resting to be overturned, and in the fall the truss was so damaged that it was not considered worth while to test it again. As compared with the former truss the cost was considerably less, being £3. 14*s.* 8*d.*

The accompanying photographs [figs. 14, 15] show the apparatus.

The experiments are by no means conclusive, but I think that they show, so far as they have gone, that it is possible to introduce considerable economy into the design of trusses made of timber, and that the subject of the best design has not yet been fully exhausted in trade practice.

The method of applying the test was suggested to me by Captain Gaynor, R.E., who took the greatest interest in the experiments, and whose assistance, as well as that of Captain Joly de Lotbinière, R.E., I take this opportunity of gratefully acknowledging. The method of testing is of course capable of application to any beam, girder, or truss under transverse strain.

APPENDIX.

Formulæ for Calculating Scantlings in Roofs of Timber

King-post and queen-post trusses.

Here W = weight of roof covering + snow
" " common rafters
" " purlins
" " principal
" " ironwork (see below)
" " wind pressure or other occasional load.

} Borne vertically by one principal rafter

w_c = weight of tiebeam + ceiling + king-post + two struts, or ditto ditto + two queen-posts + straining beam + straining sill + struts.

θ = inclination of the roof to the horizon.

For a king-post truss :—

Thrust on heel of principal $=(\frac{3}{16}W+\frac{5}{16}w_c)$ cosec θ
Tension in tiebeam . $=(\frac{3}{16}W+\frac{5}{16}w_c)$ cot θ
Thrust on strut . . $=\frac{5}{16}W$ cosec θ
Tension in king-post . $=\frac{5}{8}(W+w_c)$

For a queen-post :—

Thrust on heel of principal $=(\frac{3}{15}W+\frac{11}{30}w_c)$ cosec θ
Tension in tiebeam . $=(\frac{3}{15}W+\frac{11}{30}w_c)$ cot θ
Thrust on strut . . $=\frac{W}{6}$ cosec θ
Thrust on queen-post . $=\frac{W}{6}+\frac{11}{30}w_c$
Thrust on straining beam $(\frac{11}{20}W+\frac{11}{30})$ cot θ
Thrust on straining sill $=\frac{W}{6}$ cot θ

Ironwork in trusses 20 lbs. per principal rafter

Strap and plate at foot of rafter in a timber truss, when the strap is at right angles to the principal.

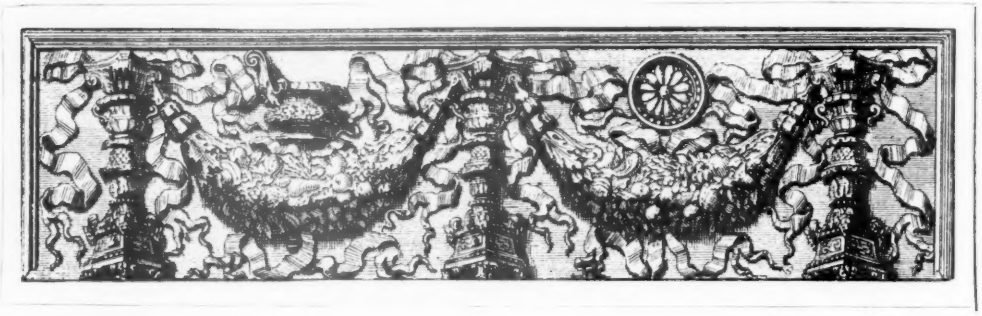
If P=thrust on principal, A=sectional area of each limb of the strap, r_t=7 tons per square inch =safe stress in this case.

$$A=\frac{P \cot \theta}{2 \times r_t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

As regards bearing plates on tiebeam and principal, b being the breadth of those beams, =length of plate, r_c=1,200 lbs. per square inch for fir.

$$l=\frac{P \cot \theta}{b \times r_c}$$

N.B.—If the strap is inclined to the principal at a less angle than 90°, find the value of the tension by triangle of forces, the hypotenuse of the triangle representing the tension on the strap found in (20).



THE LATE THOMAS HAYTER LEWIS, F.S.A.,

Emeritus Professor of Architecture.

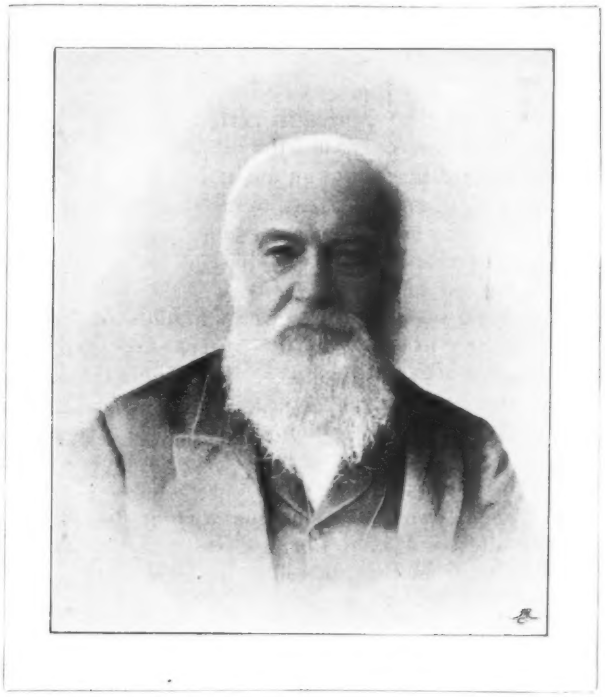
THE late Thomas Hayter Lewis began his professional career as a pupil in the office of Joseph Parkinson, of 41 Sackville Street, and he afterwards entered that of Sir William Tite, with whose nephew, Arthur Green, he was engaged on the working drawings of the Royal Exchange, which was then being erected. About, or during, this period he competed successfully for the Silver Medal of the Royal Academy, gaining it for a measured drawing of the façade of the Oxford and Cambridge Club, Pall Mall. He entered into partnership with Thomas Finden, the brother of the engraver, in 1849, and he was engaged in the active practice of his profession for the following twenty years, ten only of which were in partnership.

Although the Professor attained to a great age, the period during which he practised was comparatively short; he devoted much of his time to travel and literary work, and after the death of Mrs. Lewis in 1869 he gradually gave up all the more active duties of his profession. He nevertheless carried out many works of interest and importance, although comparatively little of ecclesiastical work; but among his church restorations may be mentioned Staplehurst, Horley, Willen, Dunkirk, and S. Martin's-in-the-Fields, London. But the work with which he most identified himself, and the initiation of which was largely due to his exertions, was that of the restoration of S. Bartholomew the Great in the City. His report on this church, published in 1863, and the pamphlet by James Henry Parker, for which he prepared the illustrations, formed the starting point of the work, and the fund then in consequence raised enabled him to complete the Norman arcade of the apse and to save the north aisle, then in imminent danger of falling, without reconstruction. But these works, together with those required for lowering the level of the accumulated earth in and around the church, and others equally necessary, exhausted the fund, and it is but recently that other hands have been enabled to resume the work he so ably began.

He erected several large country houses in the neighbourhood of London, such as The Hall, Warninglid, Sussex; Staplehurst Place, Kent; Stone Lodge, Horsham; The Knowle, Brenchley; Denham Lodge, Uxbridge; and one at Geelong, Australia, much of the prepared material for which was sent out from England. He was architect for the cross in front of Netley Hospital, erected as a memorial to the medical officers of the Army who fell in the Crimea, the foundation-stone of which was laid by H.R.H. the Prince of Wales. He added the large chapel and a music-room, with a remarkable open timber roof, to Gilbert Scott's Infant Orphan Asylum, Wanstead, as well as a chaplain's house and lodges. At Chesham he erected the village hospital, and at Staplehurst the Board Schools—among the first in

England—of rag and terra-cotta. Several large wharves and warehouses, demanding very considerable knowledge of construction, were carried out by him in London, such as Hedge's Wharves at Wapping, Reed's Upper and Lower Wharves, Bermondsey, and Zetterquist's Factories, Blackfriars; he to a great extent rebuilt Messrs. Hoare & Co.'s Red Lion Brewery and Messrs. Boord's distilleries in S. Bartholomew Close, and he was the architect of the Union Assurance Society's Offices, Cornhill.

His connection with University College, London, as Professor is referred to below. But it is necessary here to describe the part he played in dealing with the difficult problem of



From a Photo. by Mr. Barraud.

THE LATE PROFESSOR HAYTER LEWIS.

the completion of the building, particularly the South Wing, in providing the accommodation the authorities required and yet preserving intact the design of Professor Wilkins as a whole. This difficulty was greatly enhanced by the number of drawings and engravings extant, showing many divergencies, some, perhaps, without Wilkins's authority; and he devoted much time and research to discover what mode of treatment would most accord with Wilkins's discoverable ideas.* These designs differed considerably in the arrangement of the internal angle of the wings and main building, the central feature of the façade of the wings, and in several minor details, and there seems but little doubt that the arrangement he eventually carried out was the best that could be adopted, and in no way disturbed the unity of the original

* Report on North Wing, University College (p. 15). Privately printed.

conception. He also prepared the designs for the North Wing, containing the Slade and Physiological Schools, with the chemical laboratories in the rear; but although the foundation-stone was laid by Earl Granville, before his retirement, it was only after his retirement that the work was carried out.

Of his great work, the Panopticon, it is not necessary to speak in much detail; the building itself has been destroyed by fire, but full information as to its peculiarities will be found in the Paper he himself contributed to the Institute. Its later years of use, or degradation to the purposes of a music-hall, before its destruction, might make many forget that it was erected at first purely as a technical school for chemistry, electricity, &c., the admission of the public to the lectures being distinctly subservient to the main object. The names of the original promoters, such as Samuel Gurney, F. Marrable, and E. M. Clarke (father of Mr. C. Purdon Clarke, C.I.E.), are sufficient warranty for this; but the scheme eventuated in failure, and the architect received little, if any, compensation for all his skill and labour. The principal thing to remark about the building, apart from its perfect construction, was the novel style in which it was designed—Egyptian Saracenic—and the profusion of decoration employed throughout. Marbles, mosaic and painted tiles, all in an unfamiliar style, had to be drawn full size by the designer, who had as well, to a great extent, to instruct the workmen. Although at the time of the erection of this building he was in partnership, the character of the work precluded him from receiving any assistance, and the whole credit for the inception, designing, and completion of the building are due to him personally.

Many years after this work was done he received a commission from the Khedive to make designs for a hall on similar lines to be erected in Cairo, and he prepared and sent out to Egypt complete working and decorative drawings; but whether or not the building was erected is uncertain. He also prepared, on the instructions of the Crystal Palace Company, a design in colour for the case of a huge organ to be erected in the main transept the full height of the building, but the organ was never built. He was not favourable to the system of open competitions, but he sent in a design, on invitation, for the Natural History Museum, and also one for the Cambridge Town Hall under similar circumstances. He had an extensive practice as a consulting architect and arbitrator, and he held the position of architect and surveyor to several Companies in the City, as well as to the Metropolitan Fire Brigade, until it was absorbed by the Board of Works.

He was elected in 1864, in succession to the late Professor Donaldson, Professor of Architecture at University College, London, and delivered his inaugural address the next year; and in 1871 became the Dean of the Faculty of Arts. His lectures, which were most carefully prepared, were very detailed, and were illustrated by diagrams taken in a large part from his own studies, and these lectures were much appreciated by a long succession of students. He resigned the position through ill-health in 1881, when he was elected Emeritus Professor.

His travels were frequent and extended, and it is difficult to put them in proper order or to describe them. He went on his first great tour through France, Italy, Sicily, and Greece in 1841–42 with Arthur J. Green (nephew to Sir W. Tite) and Horace Jones, and they were subsequently met or joined by John Whichcord and Ewan Christian. Whether during this tour he visited Cairo appears uncertain, but is probable, as it seems unlikely that he would have erected the Panopticon in the style he did—Egyptian Saracenic as distinguished from Alhambresque—without a previous study of the buildings in Cairo; and, besides, the years following 1842 must have been too much occupied in establishing himself in practice to allow of an extended tour in the East. In 1850 he was in North Germany, where he was deputed to make a survey of the City of Hamburg with a view to reporting on its condition as modified

by the partial rebuilding after the great fire. During the years from 1859 to 1869 he made several visits to the south of France, extended to Algeria, and after that period he resumed his visits to Egypt, Palestine, and Greece, as well as, for the purpose of his *Holy Places*, Constantinople, Spalato, and Rome. His last visit to Greece seems to have been in 1884, when he was accompanied by his only son, the Rev. Edward Lewis, who predeceased him by only a few months.

Of his connection with the Institute, and of the position he held in it, it is not necessary to speak at length, for his history runs through the record of our TRANSACTIONS and JOURNALS for over fifty years. He became an Associate in 1845, and a Fellow in 1852. In 1859 he was appointed Honorary Secretary in conjunction with C. C. Nelson. He at once set to work to attempt, so far as possible, to heal the feud which then ran high between the Classic and Gothic men, and a meeting was held at his chambers, which was attended by W. Tite, G. G. Scott, and other principals on either side, with the happy result that in 1859 and 1860 several of the leaders of the Gothic party joined the Institute, and were followed by many of the juniors. He did not hold the office for long, as the Honorary Secretary of those days had practically the whole of the correspondence and TRANSACTIONS to attend to, as well as to supervise in part the Library duties, which were very onerous. He was twice a Vice-President, and it was only failing health which compelled him to refuse to allow himself to be nominated for the Presidentship in succession to Mr. G. E. Street. In his letter to the Institute, dated 27th February 1882,* he says, in reference to his proposed nomination:—"When I declined the office last year I thought it very possible that travel and rest might enable me to perform my duties as Vice-President, and that when Mr. Street's term of office expired I might perhaps find myself strong enough to be his successor. . . . But the rest I thought I should have as his Vice-President was cancelled by his lamented death. . . . I feel, therefore, compelled in justice to my colleagues and the members . . again to decline the honour of being nominated as President." To him was to a great extent due the inauguration of the Voluntary Examinations; and it was during the period of his Hon. Secretaryship that the scheme was formulated and the details worked out in conjunction with the late A. A. Ashpitel, John Papworth, Professor Roger Smith, and others.

He was always a careful and observant sketcher, and disliked the use of the straight-edge, the camera-lucida, and other mechanical contrivances; he considered that they induced carelessness, and by saving either labour or time made the study of the building, to which the sketching was a means rather than an end, superficial. Some of his early pencil sketches of Italian interiors are models of accurate perspective. A large number of his drawings have been published in the Architectural Publication Society's *Dictionary*, to which he was a large contributor, but being executed in chalk lithography the reproductions do not do justice to the originals. Some of his sketches are to be found in the *Architectural Association Sketch Book* and the TRANSACTIONS of the Institute.

The following list of papers read by him to the various Societies with which he was connected, although doubtless incomplete, shows the wide range of his studies and his intimate knowledge of every branch of our profession, from Construction to Archæology. Before the Institute he read papers on the "Panopticon" (1853), "Remarks on Domes" (1857), "Experiments on Concrete" (1857), "Construction of Domes" (1859)—this being one of the last papers read in the old Grosvenor Street rooms of the Institute—"Researches on Colour and Coloured Decoration" (1862), "Fireproof Materials and Construction" (1865), "Notes on Celtic, Roman, Moorish and other Remains in Algeria" (1868), "Architectural Education"

* *Proceedings R.I.B.A.* 1881–82, p. 152.

and "On Fireproof Floors"—within two days of each other—(1871), "On Ancient and Modern Egypt" (1875), "Persian Architecture and Construction"—in conjunction with Mr. C. Purdon Clarke—(1881), and "Notes made during Two Tours in Greece" (1887). Before the Architectural Exhibition he read Papers on "Saracenic Architecture" (1859) and on "The South of France" (1863); to the Architectural Photographic Society a Paper on Cairo (1859), and to the Architectural Association on Architecture in France (1864). An inaugural address on "The Fine Arts, and their Connection with Education" was delivered by him at University College, London, and afterwards printed in pamphlet form.

His published works are not numerous, but show the same broad scope of his attainments and observations. In conjunction with Mr. G. E. Street he re-edited and practically re-wrote the article on Architecture for the ninth edition of the *Encyclopædia Britannica*, Mr. Street confining himself to the Gothic portion of the article; and it is worthy of note that the Professor, in the main, corrected the proof-sheets when travelling in Africa. His principal work, *The Holy Places of Jerusalem*, illustrated from photographs taken by Lord Kitchener of Khartoum (then Lieutenant Kitchener), is a most exhaustive study of the subject, dealing with the theories of Fergusson and others; and with his practical and archæological experience, the result of his testing them on the spot, with the actual sites and buildings, was unfavourable to many previously accepted theories. For this task he was peculiarly fitted by his intimate knowledge of Saracenic Art and his researches in the literature of the subject. He was for long an active supporter of the Palestine Exploration Fund, and, with Sir C. W. Wilson, he annotated Procopius's account of the buildings of Justinian, and published the results. Among other pamphlets may be mentioned the "Boorg ez Ziffer, Cairo," the "Employment of Artistic Materials in the Architecture of Houses and Hospitals," the "Castles of Sandown and Sandgate," "Notes on Masons' Marks," &c.

In the Societies associated with the Institute, such as the Royal Architectural Museum and the Architects' Benevolent Fund, he took an active personal interest, as well as subscribing largely to them according to their requirements; and by many other institutions or charities not directly connected with our profession he will be greatly missed.

Although most of his professional associates and friends have predeceased him, there are still many members left who, from personal knowledge of him, will always respect his name and revere his memory; whilst the record of his life's work which he has left behind him in the annals of the Institute will enable others, who did not know him so intimately, to appreciate the loss his profession has sustained by the passing of Thomas Hayter Lewis.

J. Tavenor Perry.

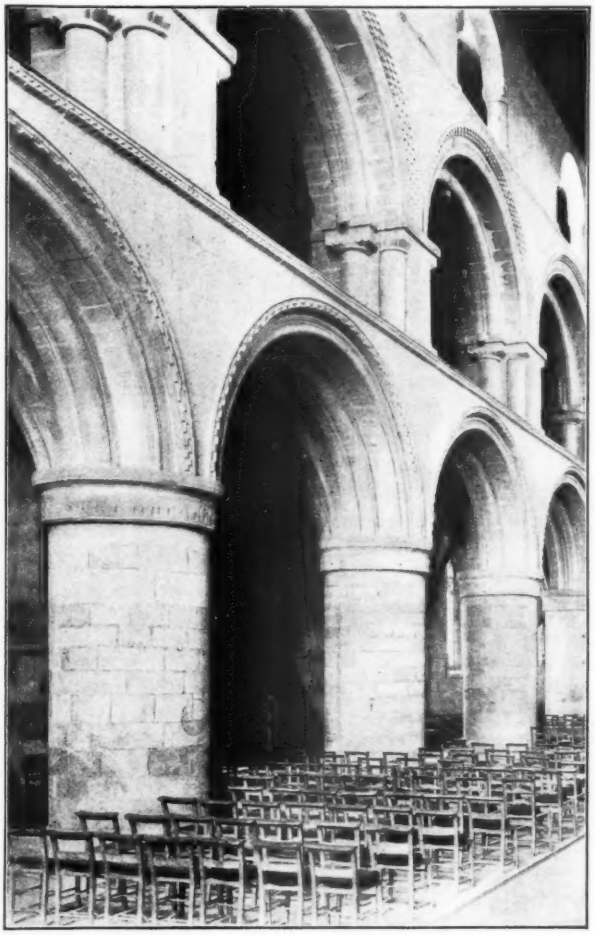
*** Mr. Henry Lovegrove [*A.*] writes that it may interest members to know that Professor Hayter Lewis was sometime Master of the learned Freemasonic Lodge, Quatuor Coronati, with which many members of the Institute are associated.

REVIEWS.

SOUTHWELL MINSTER.

The Cathedral Church of Southwell: a description of its fabric, and a brief history of the Episcopal See. By the Rev. Arthur Dimock, M.A. 8o. Lond. 1896. *Price* 1*s.* 6*d.* [*Messrs. George Bell & Sons, York Street, Covent Garden, W.C.*]

Mr. Dimock has written a well-arranged handbook, in which he gives, first a history of the building, then a description of the exterior and interior in chronological order, and concludes with an account of the adjacent palace and of the dissolution of the old Chapter. The illustrations are well chosen and good.



S. B. Bolas & Co., photo.

NAVE, NORTH SIDE OF ARCADE, SHOWING PART OF TRIFORIUM.

Those who are not acquainted with Southwell may begin by taking note of its long association with York, an association which only ended in 1841, when the minster was transferred to the diocese of Lincoln. Southwell grew up in Saxon times round several wells, which can still be traced, and was chosen by the Archbishops of York as their southern headquarters. It is suggested that Southwell was preferred to the neighbouring borough of Nottingham because Nottingham, as one of "the five burghs," was too turbulent for the calm course of ecclesiastical life. Soon after 1000 "that rude Anglo-Saxon church was built which supplanted some other of which we have no information" (p. 6). About a hundred years later the minster was rebuilt; the magnificent Norman nave and towers date from this period. Archbishop Walter de Gray built the choir about 1240. The Chapter-house was built some fifty years later, and the rood screen was carved in the first half of the fourteenth century.

The perusal of Mr. Dimock's handbook makes clear once more the obvious fact that many ancient buildings exercise one kind of attraction upon the mind which modern architects cannot hope to rival. The assemblage on one site of structures erected at different dates appeals to the historical imagination, and not immediately to that æsthetic perception of which the architect, so far as he is an artist, is the minister. The designer who should succeed even for the moment in producing such an effect would have to employ scenic artifices, and these can pass muster only for a time. When, for example, the details of different styles are assembled together without being brought into harmony under the influence of a dominating conception, the result is like that which arises when the English of to-day is interlarded with phrases, now antiquated, taken from Elizabethan writers or from the Authorised Version. So, with building, in seeking an unnatural emphasis, nine men out of ten fall into the bizarre and incongruous. I should be sorry if, in their turn, the beauties of Southwell were worked up as purple patches into fustian.

And yet there is one part of Southwell Cathedral which seems, in an especial manner, to contain the germ of future developments, and I venture to commend it to those who are attracted by such possibilities. The arcades of the Norman nave—an illustration is given herewith—stand half-way between the classic manner out of which they arose and the pointed Gothic into which they passed. Is there any reason why the round arch and the broad treatment of details employed by the Normans should not furnish a background for that scientific treatment of the figure which is usually confined to classical design? I cannot but think that a serious mistake in Fergusson's

Laughton, Southwell, photo.

CAPITALS OF NORMAN PILLARS TO EASTERN ARCH OF TOWER.

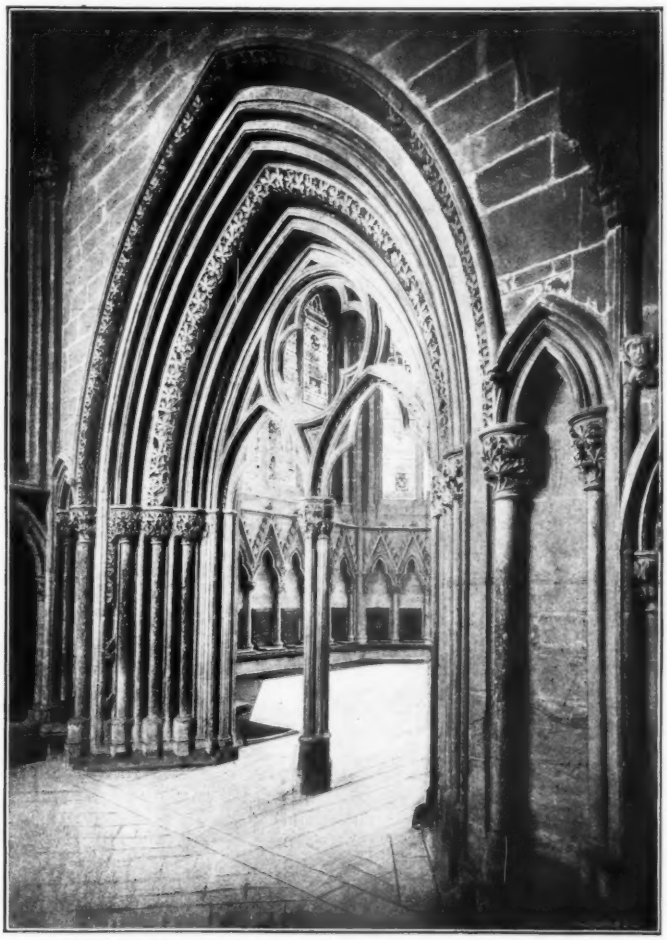
History of Architecture has been the unacknowledged source of some of the hesitancy with which architects have approached this matter. May I make a short historical digression?

Fergusson separates Byzantine from Romanesque and Norman architecture. I imagine, on the contrary, that the architects of the new capital of Constantine set the melody of which the Romanesque and Norman styles are variations. By Romanesque here I mean the buildings in the Roman style outside Rome. The buildings of Rome scarcely ever shook off the classical tradition. Outside Rome, however, whether at Ravenna or in Sicily (*cf.* Fergusson, p. 809), much work was done also by Greeks who followed the Byzantine methods; and by Byzantine I understand classical at second-hand. The sculpture of capitals and the use of mosaic as they are found in Santa Sophia are repeated in Norman and Romanesque buildings in such a way as to suggest that the same artistic tradition was at work over a wider area than is usually thought. The capitals of the Norman pillars to the eastern arch of the tower at Southwell illustrate this connection. And here, in passing, I should like to draw the attention of architects to the Norman font of the Lenton Priory Church, now preserved in the Lenton Parish Church. It is very much in the same style as the capitals illustrated, and is perhaps by the same hand. The font, I may say, is a very fine example of Christian symbolism. We are only concerned now, however, with one fact; in one of the panels there is represented a building in the Byzantine style—and this is interpreted as the Church of the Holy Sepulchre at Jerusalem. It seems probable that the mason who carved the font had either been there himself or had been supplied with drawings of the building. At any rate, this is a somewhat striking coincidence.

But why should we try to construct in imagination a new style in which mediæval methods should be adapted to a more scientific treatment of the figure in sculpture and mosaics? We have already seen its arrival. The Imperial Institute

and the Birmingham Assize Courts have been two of its heralds in secular architecture. At Paris, St. Eustache and St. Etienne du Mont have been interesting essays of the same kind in the field of church building. But the new Roman Catholic Cathedral of Westminster promises to be the most brilliant example of what may fairly be called the style of the twentieth century. I hope that these reflections may not be altogether irrelevant to our neighbouring minster of Southwell, of which, after all, the Norman nave is not the least satisfactory feature.

Nottingham. FRANK GRANGER.



A. J. Loughton, photo.

DOORWAY TO CHAPTER-HOUSE, SOUTHWELL CATHEDRAL.

9, Conduit Street, London, W., 14*th January* 1899.

CHRONICLE.

Fellows elected under the Proviso to By-law 9.

At a Council Meeting of the 9th inst. the following gentlemen, unanimously recommended for Fellowship by the Council of the York Architectural Society, and found to be duly qualified according to the Charter and By-laws, were, under the proviso to By-law 9, elected Fellows of the Royal Institute, viz.:—

Charles Henry Channon, Old Maltongate House, Malton, Yorks.

William Hepper, St. Michael's Chambers, Spurriergate, York.

The Forum at Rome.

Mr. John Hebb [*F.*] writes:—

Explorations on a small scale are being carried on in the Forum at Rome by the Italian Government, who have appointed a Commission to consider and report upon the question of the rearrangement of the entire area. The Commission consists of Prof. Barnabei, General Director of Antiquities; Professor Gatti, the celebrated Latin epigraphist; the Commendatore Lanciani, Professor of Roman Topography [*Hon. Corr. M.*]; Professor Hülsen, Secretary of the German Archæological Institute; Count Giuseppe Sacconi, Member of the Superior Council of Fine Arts, Rome [*Hon. Corr. M.*]; Cav. Boni, Inspector to the Department of Antiquities and Fine Arts, Rome, and Director of Works [*Hon. Corr. M.*].

An important discovery has been made in the hemicycle in front of the temple of Cæsar of the base of an altar, or perhaps of the column dedicated *parenti patriæ*, where Cæsar's body was burned and perhaps buried. Suetonius and Cicero use the expression *bustum*, and Festus explains this word as used for the place where *mortuus est combustus et sepultus*. Five large pieces have been discovered of the frieze and cornice of the Basilica Emilia, a building which was studied by Fra Giocondo, Baldassare Peruzzi, San Gallo, and others, of which all traces had disappeared. A chamber has also been discovered in the core of the podium of the temple of Vesta. It is quadrangular, without any opening in the walls, which are of brick, probably of the time of Hadrian. It is not known whether the chamber was for the ashes of the sacred fire, or served some other purpose. Furthermore, several pieces of the Arch of Fabius and of the Arch of Tiberius have been found and placed together. A piece of a window of the upper story of the Basilica Julia has come to light, and the work is at present centred about the Via Sacra and the Rostra Vetera, of which many bits have been discovered.

The *Echo* of 30th December last states that Signor Baccelli, the Italian Minister of Public Instruction, has directed that the ornamental remains now lying in a confused mass about the Forum in Rome should be separated, classified, systematised, and replaced in their original position with all possible precision. Cav. Boni has been entrusted with the execution of this difficult work, and he has already shown his skill in reconstructing the elegant shrine standing near the temple of Vesta.

Professor Baldwin Brown's review of Dr. Ussing's Treatise on Vitruvius [p. 103] is held over for the next issue.

NOTES, QUERIES, AND REPLIES.

The Acoustic Properties of Buildings.

The Rev. Felix Shadwell, of Finningham, Stowmarket, Suffolk, contributes the following notes on the Acoustic Properties of Buildings from a speaker's point of view:—

It is well known that many churches are easier to speak in when full than when empty. The reason of this is that the congregation absorbs the sound—and often nothing more than the sound—of the preacher's voice, and checks the vibration of the main structure. Conversely, in buildings which are easy to fill with sound when empty, more effort is required when the seats are occupied—in a physical as well as in a moral sense. The resistance of the congregation has then to be overcome—and often more difficulty is encountered in making them responsive than the walls.

In a large building the resonance can be effectively lessened by the introduction of curtains or canopies, especially if hung well up in the air. When the Albert Hall was first used the resonance was so great that the sounds from the platform were confused. But when a canopy was stretched under the dome, so as to prevent any echo from it, a marked improvement was made; so that now it is one of the finest buildings in existence for the enlargement and conveyance of musical sounds.

The recitatives in oratorios are usually accompanied by a grand piano. As there are seats for

some 7,000 persons, the instrument might seem inadequate. But it is not so. The tones are clear without being feeble. It is well known also that comparatively weak voices sound much fuller and louder there than in smaller concert-rooms, while the volume of sound from a full orchestra or the huge organ is not too great for the ample space. The best place to hear is the gallery, both for solos and choruses. This is true of most large halls where music is performed. There is little doubt that a canopy under the dome of St. Paul's would greatly assist a preacher in the nave.

The custom of stretching wires, either singly or in a net-work, across the interior of resonant buildings is of little use. And the reason is plain. Wires offer very little obstruction to the sound-waves, and do not check the vibration of the main fabric at all. If anything, they tend to increase it. At any rate, if increased in number and size, so as appreciably to obstruct sound, they would themselves vibrate in the ratio of their own tension, and produce the same sort of effect as telegraph wires, or an Æolian harp, that famous but very inferior instrument of music.

Probably the worst building in the world for confusion of sound is the chapel at Keble College, Oxford. The resonance there is so excessive that the mere movement of the foot on the floor causes a loud vibration, whilst the fall of a book produces a prolonged roar. It is quite impossible to conduct a service with proper effect. The organ makes multitudinous dissonance; the singing is mostly tumultuous discord, while the majority of preachers and readers merely cause the building to rebellow to their indistinguishable utterances. Only one man was ever well heard there in the early days of the college, and he had such a harsh voice by nature that it could hardly be said to contain a musical sound. Wires have been put up, but without effect, because wires are wholly inadequate to check vibration. What is required is tapestry on the walls and thick curtains before the doors, as well as banners in the roof. If the building was composed entirely of brick or mosaic work, it would be even more resonant than it now is. The seats and wooden roof, and the pulpit and the mosaics check vibration; but the whole structure is so compact, so excellently put together, that it responds very readily to every musical sound, and in a lesser degree to every sound. The brickwork is exceedingly good, the cement is of very fine quality, and, moreover, there is a very large wall space compared with the cubical content of the building. The best part of 80,000*l.* was spent, according to report, on this edifice, and, although the decorations are lavish and there is much beauty of detail and combination of colours, the result as a place of worship is lamentable.*

St. Paul's Cathedral in London is a difficult place for a single voice to fill. It may well be doubted whether any man could be heard from the pulpit to the west door. Canon Liddon, a master of elocution, could probably make his voice travel farther in it than any one, but he certainly could not be heard by every one in the nave if the church was full. He spoke with great deliberation, in almost a disjointed and fragmentary way, and on a very high note. But the interest of his ideas filled up the pauses between the different parts of his melodious and polished sentences, and the charm of his style kept those silent and eager who might not have been constrained by his earnestness and piety to give their whole attention to his discourses.

Ulm Cathedral, though more than 500 feet long, is easy to speak in, because the interior is diversified by beautiful carved work, and the roof is comparatively low.

The mere height of many churches interferes with their usefulness as places of public worship. St. Paul's would be better if the dome was not so lofty. Cologne Cathedral and York Minster probably exhibit the same defect.

We know historically that Savonarola preached with marvellous effect in the Duomo at Florence, but we do not know that he could be heard all over the building; and, even if so, a man can often find out how to overcome the defects of a responsive fabric such as marble, of which material most churches in Italy are built.

With regard to St. Paul's, a curious result of the shape of the building may be noticed when any one is preaching in the nave. At the circumference of the dome the voice may be inaudible to any one standing there, but on advancing down the building towards the west door, it can be heard again. This is no doubt due to the fact that the sound escapes up into the dome and is dissipated there, but being confined somewhat by the roof of the nave, it becomes appreciable to the ear, though at a greater distance from the preacher.

Another large church in which sound is easily conveyed is that of St. Mary, at Bury St. Edmunds. The distance from the lectern to the west door is more than 120 feet, something more than half the entire length, but little effort is required to render words distinctly audible at the far end. The reason why the church is satisfactory in this respect is that there are a very large number of windows in it. They adjoin one another the whole way up the body of the church on both sides, so as almost to substitute mullions and glass for solid masonry. The clerestory exhibits the same peculiarity.

When builders of the "Perpendicular" period put in their broad and lofty lights in place of the narrow Norman windows, in such buildings as Southwell Minster, besides admitting more of God's first creation, they unconsciously reduced

* Keble College Chapel is much improved by the curtains ntroduced at the suggestion of the late Warden.

the vibration of the structure, and rendered it more available for intelligible worship.

Paradoxical as it may appear, a building ought to be a bad conductor of sound in order to be successful in acoustics. If it is a good conductor it approaches the nature of a bell, and therefore responds readily to any musical sound.

It is a well-known fact that the pitch of a bell may be ascertained, without percussion, by sounding near it the note on which it is cast. It hums responsive to the moving air. By analogy every building will respond more readily to some particular note than any other. If this note can be ascertained, the work of the preacher is easy. It is his wisest plan to avoid this note, because his business is to make the air carry his voice without causing the building to vibrate in sympathy. A man of experience will often be able to tell at a glance what amount of sound a church can convey without being itself roused, and on what note he ought to pitch his voice. The Church of St. Mary Redcliffe, in Bristol, is large and responsive, and loud tones are not heard distinctly. But if a man pitches his voice low and speaks slowly, he can be heard easily to a considerable distance.

Instruments of percussion to be effective in concerted pieces must be damped after each note is played, or one sound runs into the next, and the result is confusion of harmony. Thus the notes of a piano are stopped by the dampers, and a drum-player checks the vibration with his hand, to prevent the sound continuing longer than it ought.

A speaker can use no damper—unless his own arguments supply the deficiency—and the only substitute he can apply is a frequent pause, to prevent one of his words tripping up another. It would be well for every preacher and reader to know the acoustic properties of the building which he uses, and one of the simplest and most effective experiments is to speak from end to end of it when empty and then full, and note the difference of style or volume required.

It will be found that many large buildings can be easily penetrated by a high note, and as a rule that a woman's voice reaches farther than a man's, because it is higher as well as clearer. Most people who have heard children speak in a theatre will have noticed with surprise with what ease little things of four and five can make themselves heard all over a large building by merely using their natural tones.

The vocal pitch of a building is not easily discovered exactly, and in general the best way to arrive at it is to station a friend as far off the speaker as possible, who will give a sign whether the latter is audible or not.

Ancient Engineering.

Mr. J. Elfreth Watkins, C.E., in an interesting article on "Ancient Engineering" in *Cassier's Magazine* (New York), quotes the following communication from Dr. William H. Dall, of the United States Geological Survey:—

"During a visit to the Island of Jersey (Channel Islands) in 1878, while wandering over the hills, I noticed, among many dolmens scattered about, one which seemed to have never been finished. The sides stood erect, and leading up to them were inclines over which such heavy weights as the roofing slabs of the dolmens could have been raised to the positions in which we find them. It was evident that cords and rollers, with a sufficient number of sturdy savages, would have been amply sufficient for the purpose in the case before me. The thorough manner in which the clay of the inclined plane had been consolidated was evident when it was considered that the denudation of it by the elements during unknown centuries had been insufficient to noticeably reduce its level or conceal its evident purpose."

The construction of the Egyptian pyramids, Mr. Watkins considers, could have been performed by similar methods.

Take [he says] the pyramid of Gizeh, the largest of its kind, which is approximately 150 yards high and 250 yards square at the base. In building this pyramid, which is located three miles out of Cairo, two kinds of stone were used, limestone and red granite. The limestone was quarried at El Massarah, forty-five or fifty miles from Gizeh, while the red granite was brought from Assouan, near the First Cataract, over five hundred miles. Both of these quarries were located on the river Nile. In the foreground of an illustration (given by Mr. Watkins) are to be seen rafts laden with stone blocks brought from the quarries. Upon the sloping embankment blocks are being drawn on sledges, perhaps equipped with rollers, to the highest point to which the structure has been built, the inclined plane being gradually made longer and higher with earth brought from the pits on the right and left. The highest embankment necessary when the workmen reached the top course, assuming that a twenty-per-cent. grade was adopted, would have been 750 yards long, containing about seven and a half million cubic yards, if the sides of the earth embankment would stand at an angle of thirty degrees—which is not at all improbable. Assuming that one labourer could have placed 2½ yards (about twenty barrow loads) of earth on an average each day on this embankment, ten thousand men could have built it in twelve months of twenty-five working days. It is stated that a hundred thousand men were employed for twenty years in the whole work; so that, according to this calculation, the construction of this embankment would have occupied only a small portion of the total time consumed. The false work to support the walls of the interior chambers of the pyramids could also have been made of earth rather than of timber. Heavy lumber for scaffolding must have been brought over long distances, and the framing and erection of any structure of sufficient strength to bear heavy weights would have required more skill and knowledge than the building of the pyramid itself by the method above described. In the great temple of Rameses II. is a colossal statue of that king, which equals in dimensions and exceeds in weight any other Egyptian monolith, being sixty feet high and weighing 887 tons 5½ hundredweight. It was made from a single block of red granite brought from the quarries at Assouan, 135 miles distant, by the river Nile. At Baalbec, Syria, are to be found the ruins of three temples, one of which has been given the name of Trilithon, "Three-stone-temple," from the extraordinary proportions of three of the stone blocks found in it, each being over 63 feet in length, 13 feet in height, and proportionately thick. The stones now rest in a wall over twenty feet above the present surface of the ground.